Positive and negative affect are associated with salivary cortisol in the everyday life of older adults: A quantitative synthesis of four aging studies

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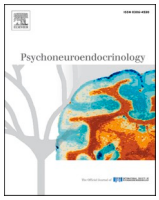

Positive and negative affect are associated with salivary cortisol in the everyday life of older adults: A quantitative synthesis of four aging studies

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ABSTRACT

Research on time-fluctuating links between positive affect and cortisol is inconsistent and mostly based on young to middle-aged samples. The current project investigated how moment-to-moment changes in positive and negative affect are associated with moment-to-moment changes in cortisol levels in older adults' daily lives and whether those associations are moderated by differences in health status (as indicated by the number of comorbidities). Affect and cortisol data collected in four separately conducted momentary assessment studies with parallel protocols were pooled to obtain a sample of N=476 individuals aged 56–88 years (M_{age}=71.9, SD=6.6; 52% female). Participants provided affect reports and collected salivary cortisol 5–7 times a day for a 7-day period and reported the presence of 13 different health conditions. Data were analyzed using multilevel models, with time since waking, daily behaviors associated with cortisol secretion, age, and sex controlled. Feeling more positive affect than usual was associated with lower momentary cortisol. In contrast, feeling more negative affect than usual was associated with higher momentary cortisol. Associations of momentary positive and negative affect with cortisol were weaker among participants in worse as compared to those in better health. Trait positive affectivity was associated with more curvature of waking cortisol profiles and trait negative affectivity was associated with smaller cortisol awakening responses. Findings suggest that HPA axis responses fluctuate with everyday changes in positive and negative affect in older adults, and that higher HPA reactivity may indicate preserved health in this age group.

1. Introduction

Not much is known about dynamic links between salivary cortisol, a marker of physiological arousal, and everyday affective states in older adults. The current study utilizes a diverse sample of 476 older adults from four separately conducted studies to systematically investigate momentary salivary cortisol levels and their associations with within-person fluctuations in positive and negative affect in a daily life context. Furthermore, a number of health conditions are known to be associated with altered cortisol secretion (e.g., diabetes, cardiovascular disease; Strahler et al., 2017). Yet, we do not know whether health status in old age might be linked with the extent to which everyday cortisol levels fluctuate in unison with affective states. Thus, we also examined health status, as indicated by the number of comorbidities, as a moderator of affect–cortisol links.

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1.1. Momentary associations between affect and cortisol

Cortisol is the end product of the hypothalamic-pituitary-adrenal (HPA) axis and is secreted in a typical diurnal pattern with high morning levels and a decrease throughout the day (Russell and Lightman, 2019). Cortisol levels rise in response to psychological stressors, particularly those including a socio-evaluative component, that is, a situation in which the self is exposed to potential negative judgment by others (Dickerson and Kemeny, 2004). Appraisal-based stress theories assume that external events result in the experience of different emotions, depending on the appraisal of the type of event (i.e., harm, threat, challenge) and one's coping resources, and that these emotional experiences, in turn, elicit physiological stress responses (Lazarus and Folkman, 1984; Nejtek, 2002). In line with this notion, studies have consistently demonstrated that cortisol levels are increased in moments of heightened negative affect in daily life in young to middle-aged samples (Hanson et al., 2000; Smyth et al., 1998; van Eck et al., 1996). For positive affect, results are less consistent. Some studies find an association between experiencing increased positive affect and exhibiting decreased cortisol in younger and middle-aged adults (Matias et al., 2011; Simpson et al., 2008; Smyth et al., 1998), whereas others do not (Jacobs et al., 2007; van Eck et al., 1996). It is object to debate whether instead of distinct emotions, overall arousal (associated with either positive or negative affect) might trigger cortisol (Abercrombie et al., 2005). Cortisol levels are influenced by a number of confounding variables aside from psychological states, such as physical activity and caffeine intake (Strahler et al., 2017). This, combined with positive affect–cortisol associations potentially being smaller than negative affect–cortisol associations, might necessitate relatively large sample sizes to have sufficient power to detect time-varying affect–cortisol links in daily life. Furthermore, most prior studies on momentary affect–cortisol dynamics utilized younger to middle-aged samples (for links between diurnal cortisol and affect in old age, see Adam et al., 2006; Piazza et al., 2013). Yet, old age is a developmental phase in which physical vulnerability increases, which makes the investigation of health-relevant physiological processes in their everyday contexts particularly important (Piazza et al., 2010). In sum, prior studies on momentary links between affect and cortisol mostly recruited younger participants and might have had limited power to detect associations pertaining to positive affective states. The current study fills this gap by investigating everyday associations of positive and negative affect with salivary cortisol in 476 older adults, pooling data across four separately conducted daily-life studies.

1.2. HPA axis reactivity and health status in old age

As a second aim, the current study examines how everyday cortisol reactivity, as measured by the strength of daily-life links between salivary cortisol and affective states, might differ by older adults' health status. Human aging is linked with elevated overall HPA axis activity, altered diurnal profiles, and impaired feedback capacity (Heuser et al., 2000; Nater et al., 2013). Dysregulation in HPA responsivity is thought to occur in the following order: after initially increased reactivity, the (aging) body is thought to overcompensate for increased total cortisol output, resulting in blunted HPA responses to external contexts (hyporeactivity; Miller et al., 2007; Zänkert et al., 2019). We also know that accumulated wear-and-tear in physiological stress systems due to chronic activation is associated with a range of health problems (McEwen, 1998), and age-related changes in HPA axis functioning are thought to occur at least partly due to worsening health (Almeida et al., 2011). Consequently, older adults who are still able to mount a cortisol response to external events might be those who do not yet show exacerbated dysregulation and are in better health overall. Thus, we assumed that there is a stronger association between increased positive and negative affect, on the one hand, and decreased or increased cortisol, on the other hand, in older adults who are in better health. We acknowledge that chronological age and health problems are correlated in older adults (Orfila et al., 2000). This manuscript focuses on health, rather than age, as a moderator because we propose that it is worse health that might be underlying reduced cortisol reactivity and not age per se.

1.3. The current study

Utilizing repeated daily life assessments obtained when participants went about their typical routines in their own environments, this study examined moment-to-moment covariations between self-reported affect and salivary cortisol. Advantages of this approach include maximized ecological validity and the ability to operationalize cortisol reactivity as a within-person process (Almeida et al., 2009). Hence, rather than comparing differences in cortisol levels *between participants* who report higher or lower affect in a given situation (or across situations), we instead compare differences in cortisol levels in moments of elevated or decreased affect *within participants*. This helps to rule out temporally stable inter-individual differences as confounding factors. We hypothesized that cortisol is decreased in moments when participants report higher levels of positive affect than what is typical for them and increased in moments when participants report higher levels of negative affect than what is typical for them. We further investigated health status as a moderator of everyday affect–cortisol links. Models control for important variables associated with HPA axis activity on the person level (sex, age; Zänkert et al., 2019) and at the momentary level (time since waking, intake of nicotine, food, caffeine, medication, or alcohol, physical activity, taking a cold shower/brushing teeth; Pääkkönen and Leppäluoto, 2002; Pauly et al., 2017; Strahler et al., 2017).

2. Methods

This project combined data of older adults aged 56–88 years from four independently conducted studies. Three of the studies were couple studies. To be able to pool all data sets (the fourth study recruited individuals), we randomly selected one partner from each couple for studies 1–3.[1] Each study is referenced below and briefly described.

2.1. Participants and procedure

Study 1 was based on 85 individuals from Vancouver, Canada, recruited for a couple study on spousal health dynamics (Pauly et al., 2019; Pauly et al., 2020; Michalowski et al., in press), aged 60–86 years (M=71.0, SD=6.2; 48% female). For 7 consecutive days, participants completed electronic questionnaires and provided corresponding saliva samples 5 times per day (waking, 30 min after waking, 11 am, 4 pm, 9 pm). Adherence was high (91% completion). Participants provided informed consent and were reimbursed with 100 CAD each. The study was approved by the ethics board of the University of British Columbia, Canada. **Study 2** included data of 77 participants from Berlin, Germany, who took part in a project on older couples' daily life (Drewelies et al., 2020; Hülür et al., 2016), aged 66–85 years (M=74.1, SD=3.6; 62% female). They collected saliva samples and answered brief surveys 7 times per day (waking, 30 min after waking, 10 am, 1 pm, 4 pm, 7 pm, 9:30 pm) for 7 consecutive days; participants excellently adhered to this protocol (98% completion). Informed consent was provided and participants received 100€ for their participation. The study was approved by the ethics committee of the Psychology department of Humboldt University Berlin, Germany. **Study 3** drew 160 participants residing in different locations across Germany (13 out of the 16 federal states) aged 56–87 years (M=72.2, SD=5.8; 50% female) from a larger participant pool of a German national longitudinal study (SOEP; Pauly et al., 2021;

[1] Findings replicate if we omit data from study 4 and instead retain both partners in studies 1–3, accounting for the interdependency of data within couples (see S-Table 1 in the Online Supplement).

Wagner et al., 2007). Participants took part in a 7-day daily life protocol, during which they completed brief questionnaires on a tablet and provided saliva samples 7 times each day (waking, 30 min after waking, 10 am, 1 pm, 4 pm, 7 pm, 9 pm). Participants gave written informed consent and were reimbursed up to 100€, contingent on adherence (which was very high: 98% completion). Ethics approval was granted by the ethics committee of the Psychology department of Humboldt University Berlin, Germany. **Study 4** recruited 154 older adults out of which 118 were aged 65–69 years and 36 were aged 83–88 years (M=71.2, SD=8.2; 50% female) from two sites in Germany (Heidelberg and Leipzig; see Kornadt et al., 2021), most of whom were part of the longitudinal ILSE study (Sattler et al., 2017). The study investigated emotional reactivity utilizing a laboratory experimental module and repeated daily life assessments. For the latter, participants were prompted at 7 times a day (waking, 30 min after waking, 10 am, 1 pm, 4 pm, 7 pm, 9 pm) over 7 consecutive days to take saliva samples and complete electronic questionnaires (adherence: 96%). Participants were reimbursed 100€ for taking part in the daily life protocol and provided informed consent. The study was approved by the ethics committees of the Faculty of Behavioral Studies, Heidelberg University, and the German Psychological Society. To evaluate statistical power, we conducted Monte Carlo simulations (n=1000) using the SIMR package (Green and MacLeod, 2016). We had >99% power to detect small-sized (0.10) time-varying links between positive/negative affect and cortisol and to detect moderately-sized (0.30) cross-level interactions of positive/negative affect with health status.

2.2. Measures

2.2.1. Positive and negative affect

Participants across all studies rated their momentary affect on a sliding scale ranging from 0% (*not at all*) to 100% (*very much*) using a number of different affect items at each electronic survey. This analysis focuses on the seven affective states for which information was available at a minimum of three across the four studies: Happy, relaxed, interested, nervous, overwhelmed, irritated, and sad. Affect was not measured 30 min post waking; thus, this measurement occasion is not part of the present analysis. A positive affect indicator was calculated as the average of the three positive affect items happy, relaxed, and interested for studies 1–3. Study 4 only included one of the positive affect items (happy) and was thus not included in models estimating positive affect–cortisol associations. Participants reported an average positive affect of 69.01 (SD=13.71) and the scale showed acceptable reliability within-person (R_C=.65) and between-person (R_{KF}=.74). A negative affect indicator was calculated for all studies averaging the four negative affect items nervous, overwhelmed, irritated, and sad (M=13.62, SD=12.63). Within-person (R_C=.69) and between-person (R_{KF}=.80) reliability was good. Positive affect was lower at the first assessment (waking) and showed relatively stable high levels throughout the day; negative affect showed declining levels throughout the day (see S-Fig. 1 in the Online Supplement). Study-specific descriptives can be found in Table 1.

2.2.2. Cortisol

Cortisol assessments were obtained from saliva samples, provided five times (study 1) and seven times (studies 2–4) a day, spaced about 2–5 h apart during waking hours. Participants used Salivettes (Sarstedt, Germany) for saliva collection and stored their samples in their fridge or freezer until they were collected by interviewers. At each university, they were frozen at –18 to −31 °C until they were sent to the Dresden LabService GmbH, Germany (Prof. Clemens Kirschbaum), for assaying. Subsequent to thawing, samples were centrifuged at 3000 rpm for 5 min. Cortisol assays were carried out using a commercially available chemiluminescence immunoassay (CLIA) with high sensitivity (IBL International, Hamburg, Germany). The lower limit of sensitivity was 0.11 nmol/L and inter- and intra-assay variation was below 9%. In between studies, IBL International recalibrated their CLIA in order to make results comparable to absolute concentrations as obtained by liquid chromatography coupled with tandem mass spectrometry (LC-MS/MS). Cortisol concentrations as determined with both CLIA assay methods are highly correlated (r>.95). This resulted in lower absolute cortisol concentrations in studies 3 and 4, as compared with studies 1 and 2. To account for assay differences, cortisol values were transformed using formulas provided by Miller et al. (2013) (see Online Supplement for details) and assay version was included as a co-variate into the models. In follow-up analyses, we z-standardized cortisol on the study-specific mean and SD; findings did not change. Cortisol values were log-transformed to correct for skewness (M = 0.64 $\log_{10}$nmol/L, SD=0.47).

2.2.3. Health status

Health status was measured as the number of health conditions reported by the participants. A sum score was calculated using a list of 13 health conditions, for which information was available across studies: hearing problems, vision problems, arthritis (rheumatoid arthritis/osteoarthritis), osteoporosis, asthma, angina/heart attack, congestive heart failure/heart disease, neurological disease (multiple sclerosis/parkinson's disease), stroke, peripheral vascular/circulatory disease, depression, thyroid dysfunction, and diabetes. This information was missing for one individual (study 2). Participants reported an average of 1.76 health conditions (SD=1.6), ranging from 0 to 9.

2.2.4. Covariates

In the electronic surveys, participants reported whether they had engaged in a number of behaviors in the past hour (for assessments during the day) or since waking up (for the morning assessment) that might influence cortisol levels. Frequencies are reported in the Online Supplement (S-Table 4). In all models, we controlled for prior

Table 1
Means, standard deviations, and intercorrelations of central study variables (study 1: N=85 participants, study 2: N=77 participants, study 3: N=160 participants, study 4: N=154 participants).

Variable	Study 1 mean (*SD*) or %	Study 2 mean (*SD*) or %	Study 3 mean (*SD*) or %	Study 4 mean (*SD*) or %	2	3	4	5	6
1. Age[a]	71.00 (6.17)	74.06 (3.55)	72.18 (5.84)	71.17 (8.25)	-.05	.29***	.07	.17***	.09
2. Sex	48%	62%	50%	50%		.13**	-.22***	.10*	-.07
3. Comorbidities[a]	1.18 (1.15)	1.70 (1.31)	1.48 (1.25)	2.42 (2.08)			-.15**	.15***	-.03
4. Positive affect	71.53 (13.67)	68.25 (12.69)	68.04 (14.12)	-				-.56***	.03
5. Negative affect[a]	16.52 (11.50)	15.04 (10.86)	15.37 (14.15)	9.50 (11.40)			-.54***		.13**
6. Cortisol[a]	0.88 (0.14)	0.85 (0.14)	0.57 (0.17)	0.60 (0.14)			-.23***	.13***	

Note. *SD*=standard deviation. For momentary measures, between-person correlations are displayed above the diagonal, within-person correlations below the diagonal.
[a] Means significantly differ between samples.
* p<.05.
** p<.01.
*** p<.001.

consumption of food, alcohol, or caffeine, smoking, taking medication or other drugs, taking a cold shower, brushing teeth, and engaging in physical activity. To account for cortisol's diurnal trajectory (and study differences in the timing of cortisol assessments), we further controlled for time since waking and time since waking squared. Age, sex, and assay version were included as person-level covariates.

2.3. Statistical analyses

Data were analyzed in R using the *lme4* package (Bates et al., 2015) for multilevel modeling. Raw positive and negative affect scores were divided by 100, so that they ranged from 0 to 1 instead of 0–100, to facilitate model convergence. Then, affect reports were within-person centered so that positive scores indicate that participants' momentary ratings were above their own mean (for example, they felt higher positive affect than usual) and negative scores indicate that participants' momentary ratings were below their own mean (for example, they felt less positive affect than usual; *momentary positive affect*, *momentary negative affect*). At the between-person level, affective states were aggregated across all assessments within the 7-day study period to obtain a mean for each person denoting trait affectivity (*person-mean positive affect*, *person-mean negative affect*). Momentary observations were nested within individuals and models estimated a random (i.e., person-specific) intercept. Models further allowed the association between positive and negative affect and cortisol to vary between individuals (random slope). Restricted maximum likelihood estimation was used. Time since waking, age, and person mean affect were centered on the sample mean; dummy coded variables (sex, assay, momentary controls) were left uncentered. Thus, the intercept reflects midday cortisol levels for male participants of average sample age who did not engage in any measured behaviors that could influence cortisol levels prior to saliva collection and whose samples were analyzed with the older immunoassay version. Equations for models estimating cortisol concentrations at measurement occasion t for individual i using positive affect as a predictor are included below, parallel models were estimated for negative affect (Models A):

$$\begin{aligned} logCortisol_{ti} &= \beta_{0i} + \beta_{1i} TimeSinceWaking_{ti} + \beta_{2i} TimeSinceWakingSquared_{ti} \\ &+ \beta_{3i} PriorFood_{ti} + \beta_{4i} PriorCaffeine_{ti} + \beta_{5i} PriorAlcohol_{ti} \\ &+ \beta_{6i} PriorMedication_{ti} + \beta_{7i} PriorSmoking_{ti} + \beta_{8i} PriorPhysicalActivity_{ti} \\ &+ \beta_{9i} PriorShowerBrushTeeth_{ti} + \beta_{10i} MomentaryPositiveAffect_{ti} + e_{ti} \end{aligned} \quad (1)$$

$$\beta_{0i} = \gamma_{00} + \gamma_{01} Age_i + \gamma_{02} Gender_i + \gamma_{03} PersonMeanPositiveAffect_i + u_{0i} \quad (2)$$

$$\beta_{1i} = \gamma_{10} \quad (3)$$

$$\beta_{2i} = \gamma_{20} \quad (4)$$

$$\beta_{3i} = \gamma_{30} \quad (5)$$

$$\beta_{4i} = \gamma_{40} \quad (6)$$

$$\beta_{5i} = \gamma_{50} \quad (7)$$

$$\beta_{6i} = \gamma_{60} \quad (8)$$

$$\beta_{7i} = \gamma_{70} \quad (9)$$

$$\beta_{8i} = \gamma_{80} \quad (10)$$

$$\beta_{9i} = \gamma_{90} \quad (11)$$

$$\beta_{10i} = \gamma_{100} + u_{10i} \quad (12)$$

To test the moderating effect of health status on momentary affect–cortisol associations, number of comorbidities was included in the between-person part of the model in Eqs. (2) and (12) (Models B):

$$\beta_{0i} = \gamma_{00} + \gamma_{01} Age_i + \gamma_{02} Gender_i + \gamma_{03} PersonMeanPositiveAffect_i + \gamma_{04} Comorbidities_i + u_{0i} \quad (13)$$

$$\beta_{10i} = \gamma_{100} + \gamma_{101} Comorbidities_i + u_{10i} \quad (14)$$

3. Results

Descriptive statistics and intercorrelations are described in Table 1. Older age was associated with more comorbidities (r=0.29 p<.001) and higher levels of negative affect (r=.17, p<.001). We also calculated bivariate within-person correlations of cortisol with each of the seven discrete affective states with the rmcorr package (Bakdash and Marusich, 2017). Within-person associations of cortisol with affective states were r=–.22 for happy, r=–.18 for interested, r=–.14 for relaxed, r=.10 for nervous, r=.11 for overwhelmed, r=.06 for angry, and r=.08 for sad; each p<.001. All measures assessed on a momentary basis showed considerable fluctuations within individuals (positive affect: 52% of variance situated at the measurement occasion level; negative affect: 45%; cortisol: 88%).

3.1. Momentary associations between affect and cortisol

In line with our hypotheses, participants' cortisol levels were lower in moments when they reported higher positive affect than usual (Model A; b=–0.12, SE=0.02, p<.001; see Table 2). Furthermore, participants displayed higher cortisol levels in moments when they reported higher negative affect than usual (Model C; b=0.12, SE=0.02, p<.001). See Fig. 1 for a graphical illustration of these within-person associations. At the between-person level, there were no significant associations of person-mean positive affect and person-mean negative affect, respectively, with the intercept (i.e., midday cortisol levels). Variance explained by fixed effects was 55–57% and variance explained by fixed and random effects was 68-69%.

3.2. HPA axis reactivity and health status in old age

In a next step, we introduced the cross-level interaction between number of health conditions and momentary positive and negative affect (Table 2). Health status moderated the extent of within-person associations of momentary positive affect with cortisol (Model B; b=0.06, SE=0.02, p<.001) and of negative affect with cortisol (Model D; b=–0.03, SE=0.01, p=.005). Specifically, the respective associations were more pronounced in those participants who reported better health status (see Fig. 2): As compared to participants with a higher number of health conditions, participants with a lower number of health conditions displayed lower cortisol when feeling more positive affect than usual and higher cortisol when feeling more negative affect than usual. Only in Model D (based on studies 1–4) but not in Model B (based on studies 1–3; insufficient positive affect data in study 4), there was a significant association of a greater number of health conditions with higher average midday cortisol levels (b=0.07, SE=0.01, p=.041). Variance explained by fixed effects was 55–57% and variance explained by fixed and random effects combined was 68–69%. Models including the cross-level interaction showed significantly better fit to the data (positive affect: $\chi^2(1)$=13.1, p=.001; negative affect: $\chi^2(1)$=18.4, p<.001).

3.3. Sensitivity and follow-up analyses

We decided to analyze associations of momentary positive and negative affect with cortisol in separate models, because study 4 had only one positive affect item in common with the other studies and was thus not part of the respective models (Models A and B). However, we ran follow-up analyses with studies 1–3 that simultaneously modeled both positive and negative affect as predictors to examine whether our findings hold, while controlling for the respective oppositely valenced

Table 2
Results from multilevel models examining cortisol (log10 nmol/L) using restricted maximum likelihood estimation (N=321–476 participants).

Variable	Positive affect and cortisol		Negative affect and cortisol	
	Model A *b* (*SE*)	Model B *b* (*SE*)	Model C *b* (*SE*)	Model D *b* (*SE*)
Fixed effects				
Intercept	0.50*** (0.02)	0.50*** (0.02)	0.50*** (0.01)	0.48*** (0.02)
Time since waking	–0.07*** (0.01)	–0.07*** (0.01)	–0.08*** (0.01)	–0.08*** (0.01)
Time since waking squared	0.01*** (0.01)	0.01*** (0.01)	0.01*** (0.01)	0.01*** (0.01)
Age	0.01 (0.01)	0.01 (0.01)	0.01 (0.01)	0.01 (0.01)
Sex	-0.04* (0.02)	-0.04* (0.02)	-0.04** (0.01)	-0.05** (0.01)
Person mean positive affect	-0.05 (0.07)	-0.05 (0.07)		
Person mean negative affect			0.06 (0.06)	0.05 (0.06)
Comorbidities		0.01 (0.01)		0.01* (0.01)
Momentary positive affect	-0.12*** (0.02)	-0.21*** (0.03)		
Momentary negative affect			0.12*** (0.02)	0.19*** (0.03)
Momentary positive affect x comorbidities		0.06*** (0.02)		
Momentary negative affect x comorbidities				-0.03** (0.01)
Random effects				
Intercept person	0.16***	0.16***	0.15***	0.15***
Momentary positive affect	0.20***	0.19***		
Momentary negative affect			0.21***	0.20***
Covariance intercept, momentary positive affect	0.22	0.22		
Covariance intercept, momentary negative affect			–0.07	–0.05
Residual	0.25***	0.25***	0.24***	0.24***
Model Fit				
Deviance	1894.9	1920.1	1569.8	1599.5
Marginal R^2	.55	.55	.57	.57
Conditional R^2	.68	.68	.69	.69

Note. *b*=unstandardized regression coefficient. *SE*=standard error. Marginal R^2=Variance explained by fixed effects. Conditional R^2=Variance explained by fixed and random effects. Sex was coded 0=male, 1=female. Models also control for assay version, prior food, caffeine, alcohol, and medication intake, smoking, physical activity, and taking a cold shower/brushing teeth (not shown for simplicity). Coefficients <|0.01| were rounded to 0.01 and −0.01. Models for negative affect are based on *N*=475–476 participants, models for positive affect are are based on *N*=321–322 participants.
* $p<.05$.
** $p<.01$.
*** $p<.001$.

affective state. Results are reported in the Online Supplement (S-Table 2) and replicate all findings with regards to hypothesized associations. Because some momentary covariates occurred with very low frequency (alcohol intake, nicotine intake, taking a cold shower/brushing teeth), we reran models excluding the pertaining three control variables. Findings do not change. Due to known cultural differences in HPA axis reactivity (Miller and Kirschbaum, 2019), we also ran models controlling for study country (Canada, Germany) which did not influence findings. In additional follow-up analyses, we explored whether the associations between positive or negative affect with cortisol differed by measurement occasion (1 through 5 for study 1; 1 through 7 for studies 3–4); this was not the case. We also investigated whether there would be any lagged associations between affect and cortisol, over and above the concurrent associations. Cortisol levels were not associated with reports of positive affect or negative affect at the previous assessment point. Yet, these findings should be interpreted with caution due to the relatively large temporal distance between assessments (2–5 h).

Furthermore, we recalculated the comorbidity index excluding health conditions that differed by at least 20 percentage points between samples (thyroid dysfunction, arthritis; see S-Table 3 in the Online Supplement for distribution of health conditions within and between samples). Using this revised comorbidity index did not change findings (moderation of positive affect–cortisol link: b=0.06, SE=0.02, p=.008; moderation of negative affect–cortisol link: b=–0.03, SE=0.01, p=.005). We also tested health conditions separately to explore whether some of them uniquely contributed to weaker affect–cortisol links (see S-Table 3). Adjusting for multiple comparisons (Bonferroni correction), only hearing problems significantly moderated the association between momentary positive affect and cortisol levels. Finally, using the approach outlined by Doane and Adam (2010), we tested associations of person-mean affective states and health conditions with indices of the diurnal trajectory of cortisol (CAR, slope, curvilinearity). Results are reported in S-Tables 5 and S-6 in the Online Supplement. Higher person-mean positive affect was associated with more curvilinearity of the cortisol rhythm during waking hours (b=0.01, SE=0.01, p=.022). Higher person-mean negative affect was associated with a lower average CAR (b=–0.09, SE=0.04, p=.038). Participants with a higher number of health conditions showed a flatter diurnal slope (b=0.01, SE=0.01, p=.002). Please see the Online Supplement for findings with respect to discrete health conditions.

4. Discussion

Well-powered studies on momentary affect–cortisol associations as they occur in daily life are rare, particularly when it comes to *positive affect*, and have primarily focused on younger to middle-aged samples. The central aim of the present study was to fill this gap to systematically examine links between positive and negative affect and everyday salivary cortisol in a sample of *N*=476 older adults, which resulted from pooling data across four separate samples from Canada and Germany. We found that cortisol levels were lower in moments when participants reported feeling higher positive affect than was typical for them. We also found that cortisol levels were higher in moments when participants reported feeling higher negative affect than was typical for them. Associations of cortisol with positive and negative affect were moderated by health status in such a way that associations were more pronounced among participants with a lower number, as compared to those with a higher number, of health conditions.

4.1. Momentary associations between affect and cortisol

Daily life fluctuations of positive and negative affect co-varied with momentary cortisol levels. Using an older adult sample, we built on research with younger to middle-aged samples by demonstrating that everyday affective experiences matter, and that they are reflected in health-relevant physiological processes. In line with existing literature, we found that cortisol levels were elevated in moments when older adults reported higher negative affect than usual (Hanson et al., 2000; Smyth et al., 1998).

Dovetailing with meta-analytic findings from Joseph et al. (2021), we also found that cortisol levels were decreased in moments when older adults reported higher positive affect than usual. Some prior studies have not found links between time-varying positive affect and cortisol among younger samples (e.g., Jacobs et al., 2007). One reason might be power limitations, because associations between positive affect and cortisol might be smaller than associations between negative affect and cortisol, and because salivary cortisol as collected in an everyday context can be influenced by multiple psycho-behavioral factors over and above affect, including taking medication, exercising, and drinking coffee (Strahler et al., 2017).

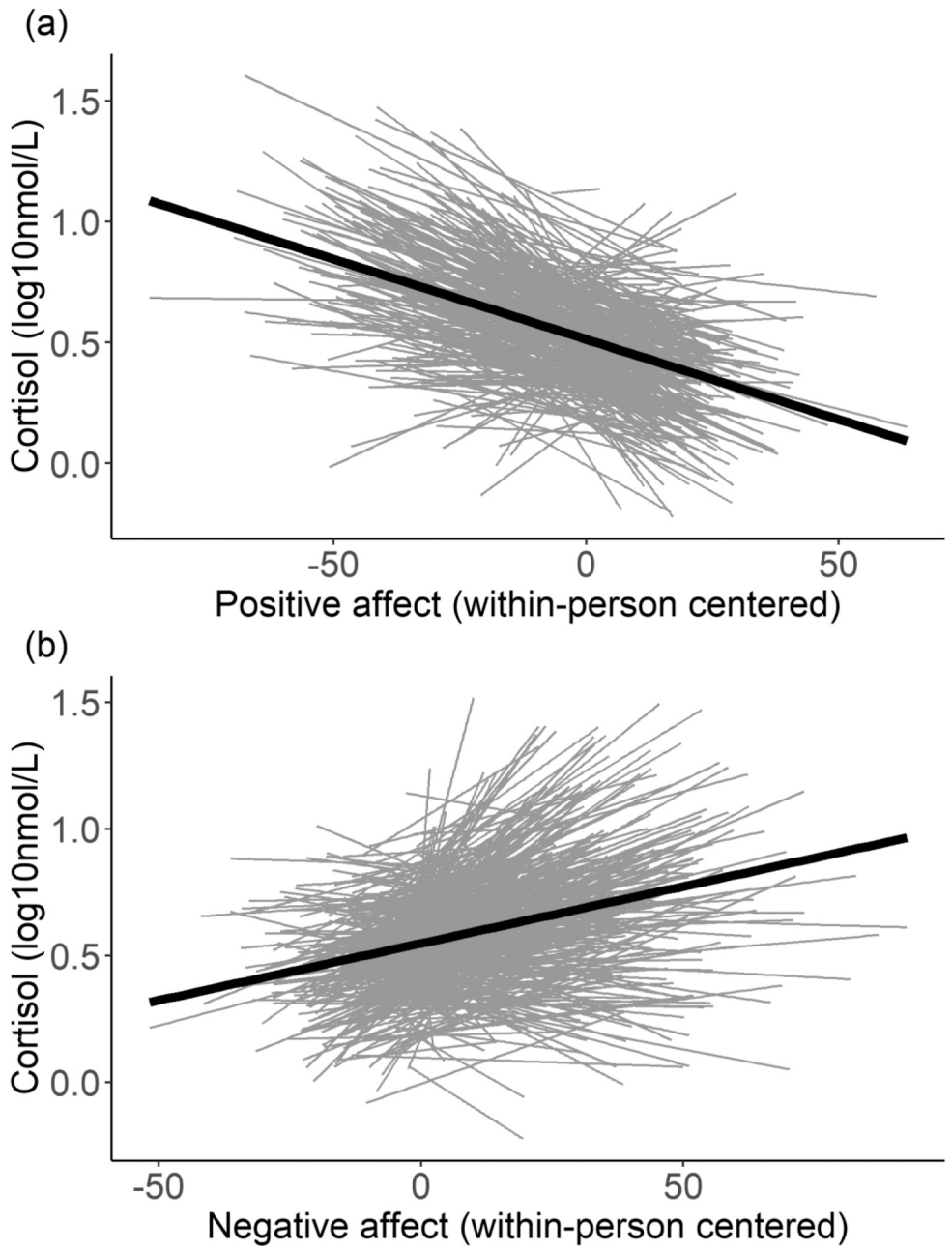

Fig. 1. Model-implied within-person associations of positive and negative affect with salivary cortisol. Note. Cortisol was lower in moments when older adults reported higher positive affect than usual (a) and higher in moments when older adults reported higher negative affect than usual (b).

Another reason might be that the link between positive affect and cortisol only becomes visible (or becomes stronger) with age. Grounded in the perception that there is only a limited time left to live, older adults are thought to focus on optimizing their everyday emotional experiences (Carstensen et al., 2003) and, concordantly, older age tends to go along with better affective well-being (Carstensen et al., 2011). Thus, the down-regulation of physiological arousal by positive affective states might gain importance or become more effective in older, as compared with younger, adults. A study testing this idea more directly could examine age differences in momentary positive affect–cortisol links across the adult lifespan (controlling for health status), and whether such differences can be explained by age-associated strengths relevant to emotional well-being (e.g., positivity bias; Charles, 2010). Future research should also assess characteristics of the events that precede affective states in daily life (e.g., complexity, choice, motivation; Isaacowitz et al., 2017; Wrzus et al., 2013). For example, the overpowering hypothesis assumes that age-associated advantages in reactivity might only be visible when dealing with simple and circumscribed events, but not when confronted with complex and more demanding situations (Wrzus et al., 2013).

We did not find associations between person-mean positive or negative affect (aggregated over the 7-day study period) and average cortisol levels at midday. However, in exploratory follow-up analyses, we investigated links between trait affectivity and daily cortisol profiles during waking time. Higher trait positive affect was associated with more curvature of the cortisol rhythm. Furthermore, replicating findings of Polk et al. (2005), participants with higher trait negative affect showed lower morning rises of cortisol. In general, research with younger to middle-aged samples seems to suggest that trait positive affectivity rather than negative affectivity might be more consistently related to HPA axis activity (Miller et al., 2016; Steptoe et al., 2007). Using an older adult sample, Ong et al. (2011) extended this research by

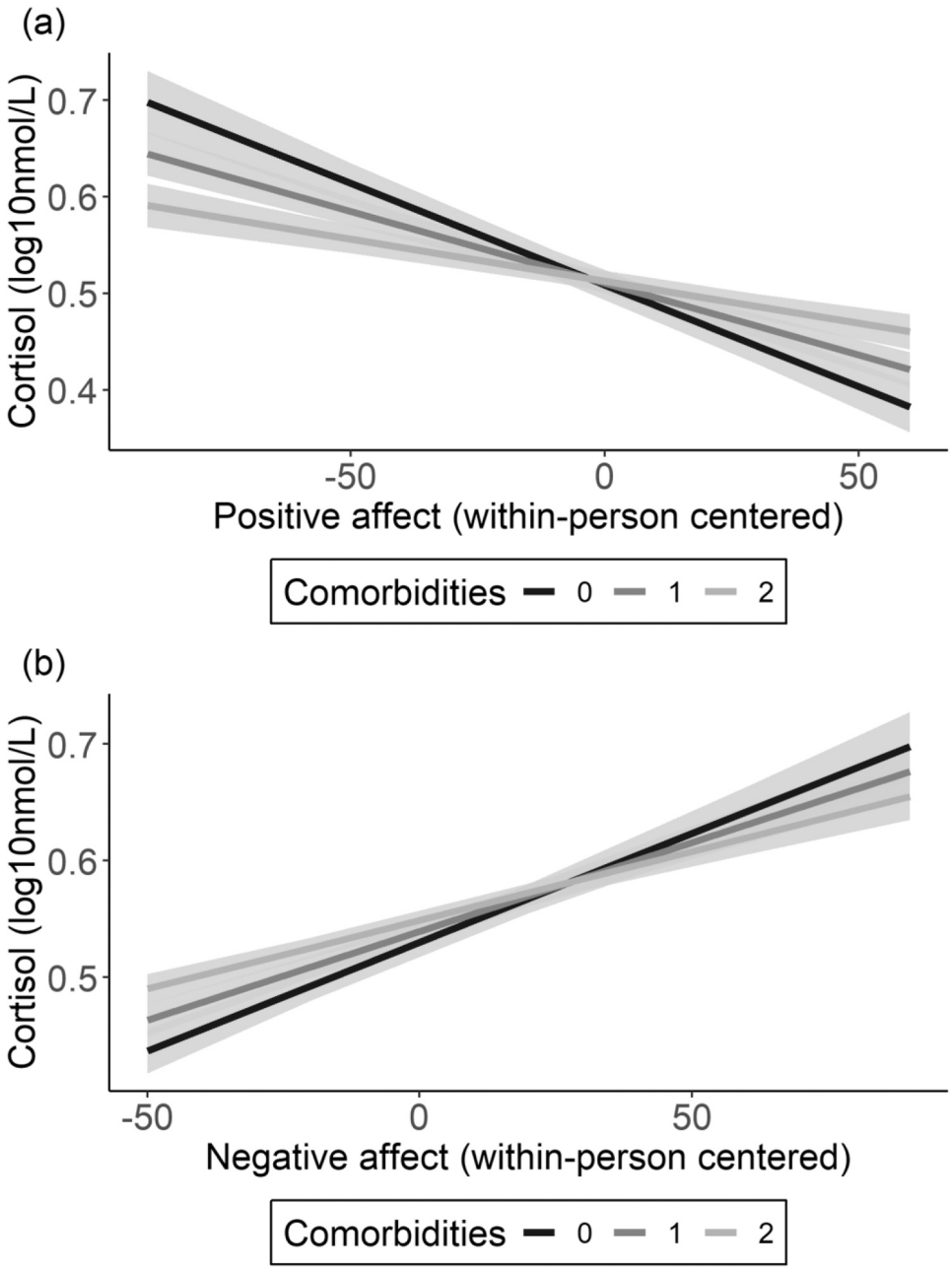

Fig. 2. Moderation of associations between affect and cortisol by health status. Note. Older adults with a higher number of health conditions showed reduced cortisol reactivity, i.e., they displayed a weaker association between greater positive affect and lower cortisol as well as a weaker association between greater negative affect and higher cortisol.

showing that HPA axis dysregulation (as indicated by flatter diurnal cortisol slopes) following spousal loss was mediated by decreases in positive affect. The projects included in this manuscript purposefully selected affect items that showed considerable day-to-day variation in the experience realm of older adults, because we were interested in state fluctuations. Future research might include items that vary less in daily life but could be more important for enduring associations with physiological arousal such as vigor (e.g., lively, energetic), hostility (e.g., angry, resentful), anxiety (e.g., on edge), depression (e.g., downhearted), and fear (e.g., afraid). Furthermore, a study with adolescents suggests that high arousal positive affect, rather than low arousal positive affect, might be associated with a steeper cortisol slope (Hoyt et al., 2015).

4.2. HPA axis reactivity and health status in old age

In initially healthy individuals, prospective studies have shown that greater salivary cortisol reactivity to a laboratory stressor is linked with greater risk of coronary artery disease and more rapid telomere shortening (Hamer et al., 2012; Steptoe et al., 2017). At the same time, allostatic load theory posits that long-term wear-and-tear in physiological systems, which older adults are more likely to have been exposed to, might lead to a reduced capacity to mount an adequate physiological response to external challenges (McEwen, 1998). Indeed, prior research has linked blunted cardiovascular and cortisol reactivity with worse health outcomes including obesity, downturn progression of physical disability, and lower bone density (Turner et al., 2020). Most prior studies on this topic have focused on HPA axis reactivity in the context of stress and negative emotionality. Our findings extend this research by

suggesting negative health links of cortisol hyporeactivity with respect to both positive and negative affect in old age. Specifically, we find that older adults with a higher number of health conditions, as compared with participants with a lower number of health conditions, showed a less pronounced decrease in cortisol in moments when they reported feeling more positive affect than usual and a less pronounced (not more pronounced) increase in cortisol in moments when they reported feeling more negative affect than usual. This is in line with findings from Chen et al. (2017) who demonstrated that younger and older adults who showed more pronounced cortisol responses to a laboratory stressor also displayed diurnal cortisol profiles that indicated less dysregulation in the system (i.e., higher awakening reactions and steeper diurnal slopes). Follow-up analyses examining health conditions separately did not suggest that findings were driven by a set of disparate mental or physical health impairments. Thus, it seems that worse health in general as indicated by multimorbidity (which could manifest in different ways) was associated with a lesser capacity of the HPA axis to fluctuate with momentary affective states. However, an answer to the question whether worsening health is accompanied by impaired HPA axis responsivity in old age with higher quality of evidence can only be reached with longitudinal, prospective studies that assess individuals' affective states, HPA reactivity, and health outcomes over a span of years or decades (e.g., via measurement burst design; Sliwinski, 2008), as individuals experience health status changes. We further found that multi-morbidity was not just related to less pronounced HPA axis reactivity but also to more dysregulated cortisol diurnal rhythms as indicated by a lesser decrease of cortisol levels throughout the day. This dovetails with prior research linking a number of health conditions to flatted diurnal cortisol slopes (Adam et al., 2017).

4.3. Strengths, limitations, and future directions

Strengths of the current study include the large sample size for a study that targets cortisol among older adults, the combination of data from several independently collected samples, and the daily life approach, which all enhance generalizability of findings. Another strength is the use of a relatively objective indicator of health status (i.e., the number of health conditions), which helps avoid item overlap between affect measures and measures of self-reported health. We based our manuscript on the assumption that cortisol levels increase or decrease in response to fluctuations in positive and negative affective states, which operationally defines HPA axis reactivity. This is concordant with research showing that mood mediates the association between daily stressors and cortisol (Jacobs et al., 2007; Smyth et al., 1998; van Eck et al., 1996). Yet, all investigated associations are correlational in nature and cannot be used to draw inferences about the direction of effects. For example, Hoyt et al. (2016) found that increases in cortisol were followed by subsequent increases in affective states (activeness, alertness, relaxation) in daily life. Future studies should consider a more intensive sampling protocol that allows depicting the dynamic interplay between fluctuating affective states and cortisol in a more fine-grained way. There is indication that older adults' physiological systems might react less strongly, but recover more slowly to external events (Wrzus et al., 2014). Because only a limited set of affect items was measured consistently across the four studies included in the present manuscript, we were not able to examine the role of arousal for affect–cortisol links. Prior research has demonstrated that older adults prefer low arousal positive affect (e.g., calm) over high arousal positive affective states (e.g., excited; Scheibe et al., 2013). Thus, it still needs to be determined whether the found associations hold for positive affect in general or if they vary by arousal. The four study samples differed in mean levels of age, comorbidities, and negative affect, which might have influenced between-person findings. Finally, our sample of older adults was community-dwelling and relatively healthy. Future research needs to examine the moderating role of health status on HPA axis reactivity in a more diverse sample, using other health indicators (e.g., health-related quality-of-life, activities of daily living).

5. Conclusions

State affective experiences in the daily lives of older adults showed small to moderate associations with cortisol levels. Specifically, we found that older adults' cortisol was lower in moments when they felt higher positive affect than usual and that cortisol was higher in moments when they felt higher negative affect than usual. Health status moderated within-person associations between momentary affect and cortisol in such a way that associations between positive affect and cortisol as well as negative affect and cortisol were less pronounced in participants with worse, as compared to those with better, health status (as indicated by the number of comorbidities).

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Declarations of interest

None.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.psyneuen.2021.105403.

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